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ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)

Level-4 Water Use Efficiency L4(WUE) Algorithm Theoretical Basis Document

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List of Acronyms

ATBD	Algorithm Theoretical Basis Document
CONUS	Contiguous United States
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ET	Evapotranspiration
GPP	Gross Primary Production
HyspIRI	Hyperspectral Infrared Imager
ISS	International Space Station
L-3	Level 3
L-4	Level 4
MODIS	MODerate-resolution Imaging Spectroradiometer
OCO	Orbiting Carbon Observatory
PHyTIR	Prototype HyspIRI Thermal Infrared Radiometer
PT-JPL	Priestley-Taylor Jet Propulsion Laboratory
SDS	Science Data System
SIF	Solar induced chlorophyll fluorescence
SMAP	Soil Moisture Active Passive
VIIRS	Visible Infrared Imaging Radiometer Suite
WUE	Water Use Efficiency

Contents

1 Introduction

1.1 Purpose

Plants and ecosystems have highly disparate water consumption (i.e., evapotranspiration, *ET*) needs based on their evolutionary histories, local plasticity and adaptations. Some plants are more efficient with their water use than others, subsequently fixing relatively greater amounts of carbon (C) through photosynthesis (gross primary production, *GPP*) per unit of water lost through ET. This C gain relative to water lost is termed the Water Use Efficiency (*WUE*) [*Stanhill*, 1986; *Stewart and Steiner*, 1990; *Steduto*, 1996]. During times of water shortage or drought, less water use efficient plants may be more vulnerable to stress or mortality than are plants with higher *WUE* [*Keenan et al.*, 2013]. Knowing what and where the *WUE* is of different plants and ecosystems will advance the understanding of how the terrestrial biosphere is responding to changes in climate. A relatively high spatial resolution is necessary to capture *WUE* differences in ecosystems with diverse species assemblages.

ECOSTRESS produces *ET* over the entire ECOSTRESS domain as a Level-3 product, L3(ET_PT-JPL) [*Fisher and ECOSTRESS Algorithm Development Team*, 2018]. To generate *WUE* the L4(WUE) product must ingest an ancillary *GPP* product to combine with the L3 *ET* product concurrently measured/produced during the L3 *ET* ECOSTRESS production.

In this Algorithm Theoretical Basis Document (ATBD), we describe the calculation of *WUE* and the ingestion of the *GPP* product. The theoretical basis for the ECOSTRESS *ET* is described in the ECOSTRESS L3(ET_PT-JPL) ATBD. The ECOSTRESS L4(WUE) product is a value-added product to ECOSTRESS.

1.2 Scope and Objectives

In this ATBD, we provide:

1. Description of the general form of the *WUE* equation;
2. Description of the *GPP* ancillary data ingestion.

2 Parameter Description and Requirements

Attributes of the *WUE* data required by the ECOSTRESS mission include:

- Spatial resolution of 70 m x 70 m;
- Latency as required by the ECOSTRESS Science Data System (SDS) processing system;
- Includes all geographic terrestrial regions visible by the ECOSTRESS instrument (i.e., the Prototype HyspIRI Thermal Infrared Radiometer; PHyTIR) from the ISS, with priorities to the ECOSTRESS Science Objective 1 Water Use Efficiency (WUE) target regions ("hotspots"), the ECOSTRESS Science Objective 3 agricultural regions (e.g., the Contiguous United States; CONUS), and the Cal/Val sites (Figure 1).

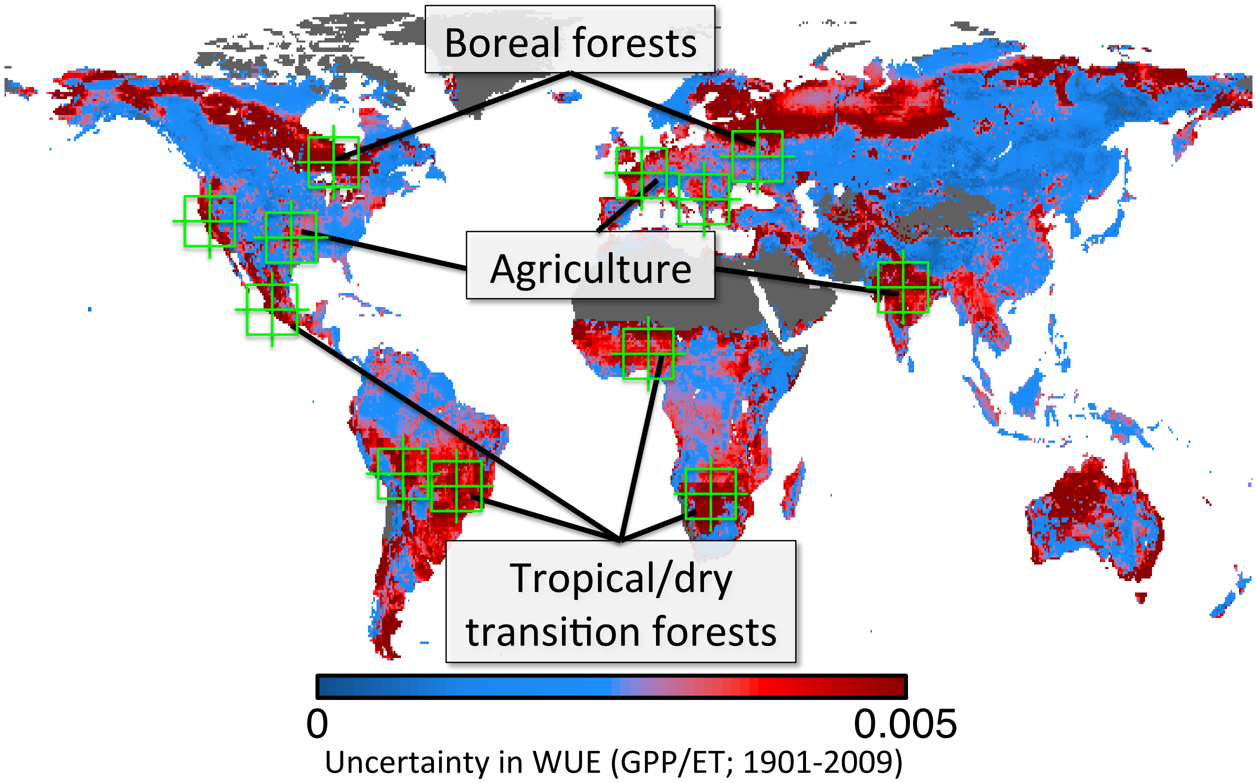

Figure 1. Uncertainty in Water Use Efficiency (WUE) from global models is highlighted in the red areas ("hotspots"). ECOSTRESS will target these regions.

3 Algorithm Selection

The *WUE* algorithm must satisfy basic criteria to be applicable for the ECOSTRESS mission:

- Physically defensible;
- Globally applicable;
- High sensitivity and dependency on remote sensing measurements;
- Relative simplicity necessary for high volume processing;
- Demonstrated sensitivity to vegetation drought conditions;
- Published record of algorithm maturity, stability, and validation.

4 Water Use Efficiency Retrieval

4.1 Gross Primary Production (GPP)

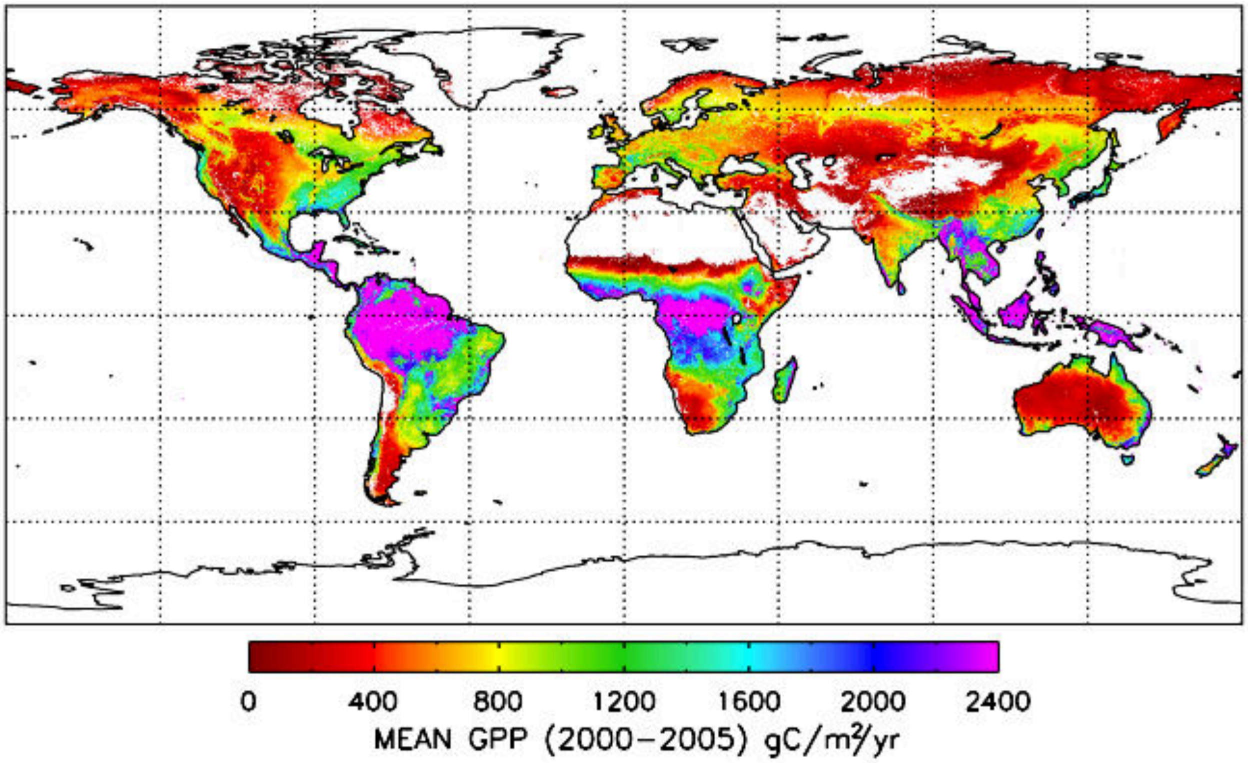

Figure 2. Gross Primary Production (GPP) from MODIS. [*Zhao et al.*, 2005]

The MODIS product is ideal for ECOSTRESS because it aligns with the other MODIS ancillary products already being ingested into the L3(ET_PT-JPL) algorithm/product, it is given at relatively high spatial and temporal resolutions (1 km, 8-day), and has been vetted in the scientific literature [*Heinsch et al.*, 2006; *Turner et al.*, 2006; *Zhang et al.*, 2012] (Figure 2).

The *GPP* product is ingested operationally into the JPL L3/L4 team's data production stream. The MOD17 8-day estimate of GPP in kilograms of carbon per square meter is multiplied by 1,000, to convert to the units from kilograms to grams, and then divided by eight to convert the time-step to daily. This daily measure of carbon uptake is divided by the L3(ET_PT-JPL) daily ET in kilograms per square meter to calculate the ratio of grams of carbon ingested to kilograms of water lost. This product is supplied as *WUE* back to the SDS for delivery to the DAAC according to the ECOSTRESS data delivery schedule.

4.2 Daily Evapotranspiration (ET)

Latent heat flux at the daily temporal scale is estimated by assuming the evaporative fraction (EF) at the time of observation remains stable during daylight hours. This fraction is calculated from instantaneous latent heat flux (AET), instantaneous net radiation (R_n) and instantaneous soil heat flux (G) retrieved from the ECOSTRESS L3(ET_PT-JPL) product [*Fisher and ECOSTRESS Algorithm Development Team*, 2018]:

$$EF = \frac{AET}{R_n - G} \tag{1}$$

Daily average latent heat flux is obtained by multiplying this evaporative fraction with the daily integration of net radiation ($R_{n,daily}$) described in the ECOSTRESS L3(ET_PT-JPL) ATBD [*Fisher and ECOSTRESS Algorithm Development Team*, 2018]:

$$LE_d = EF * R_{n,daily} \tag{2}$$

Latent heat flux represents evapotranspiration in terms of a rate of transfer of energy into water as watts per square meter. To accumulate this rate over the course of the day, latent heat flux (LE_d) is multiplied by the number of seconds of daylight between sunrise and sunset (DL). To convert this amount of energy into an amount of water, we divide by a latent heat of vaporization of 2.45 million joules per kilogram (λ). This results in daily evapotranspiration (ET) in kilograms of water evaporated per square meter over the course of the day. This is equivalent to change in height of water in millimeters.

$$ET = LE_d * \frac{DL}{\lambda} \tag{3}$$

4.3 Water Use Efficiency (WUE)

Water user efficiency (*WUE*) is defined as the ratio of the amount of carbon fixed in units of GPP (g C m^{-2} d^{-1}) per amount of water lost in units of *ET* (kg H_2O m^{-2} d^{-1}), which reduces to a daily ratio (g C kg^{-1} H_2O):

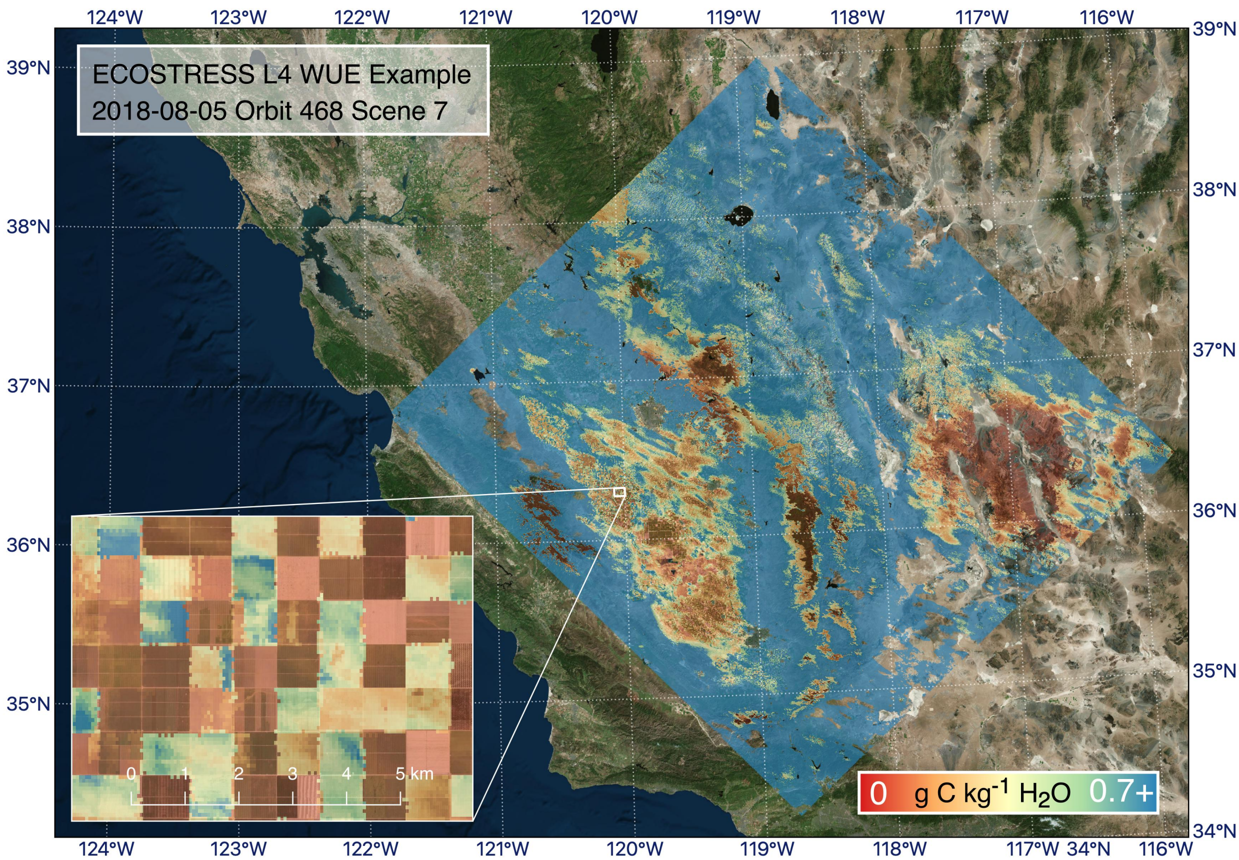

Figure 3. ECOSTRESS WUE (GPP/ET) product output example over California's Central Valley on August 5th, 2018, showing regions of low water use efficiency in red and high water use efficiency in blue.

$$WUE = \frac{GPP}{ET} \tag{4}$$

High values indicate efficient plants, and low values indicate inefficient plants. The theoretical basis and algorithmic procedures for producing *ET* are described in the ECOSTRESS L3(ET_PT-JPL) ATBD [*Fisher and ECOSTRESS Algorithm Development Team*, 2018].

An example of the ECOSTRESS *WUE* with MODIS GPP for a single granule is given in Figure 3. The accuracy of the *WUE* is dependent on the accuracies of the L3(ET_PT-JPL) and *GPP* products. Higher accuracies and precisions enable small detection differences between ecosystems.

4.4 Spatial Resolution

The L3(ET_PT-JPL) ECOSTRESS product will be given at 70 m x 70 m spatial resolution (though with caveats—see, L3(ET_PT-JPL) ATBD). The *GPP* product will be provided at a spatial resolution coarser than ECOSTRESS, e.g., 1 km x 1 km from MODIS. The *GPP* product will be sub-sampled to match the 70 m x 70 m ECOSTRESS spatial resolution both for consistency as well as use of the high resolution of the *ET* product; however, we caution analyses of *WUE* at less than 1 kilometer as the mixed resolution of the source data are between 70 m and 1 km, and the variability of the output product depends on the relative sensitivity of *WUE* to the high-resolution *ET* for any given place and time, as well as the relative sub-pixel heterogeneity of the coarse-resolution *GPP*.

5 Mask/Flag Derivation

The L3(ET_PT-JPL) quality flags are carried over identically to L4(WUE). No additional quality flags are incorporated from those provided by the ancillary *GPP* product (Table 1):

Table 1. ECOSTRESS L4(WUE) MODIS ancillary data flags and responses to poor quality.

Input product	Quality Flag	Response to poor quality
MODIS GPP	N/A	N/A

6 Metadata

- unit of measurement: units of *GPP* per units of *ET* (g C kg^{-1} H_2O)
- range of measurement: 0 to 10
- projection: ECOSTRESS swath
- spatial resolution: 70 m x 70 m
- temporal resolution: dynamically varying with precessing ISS overpass; instantaneous throughout the day, local time
- spatial extent: all land globally, excluding poleward ±60°
- start date time: near real-time
- end data time: near real-time
- number of bands: not applicable
- data type: float
- min value: 0
- max value: 3000
- no data value: 9999
- bad data values: 9999
- flags: quality level 1-4 (best to worst)

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